

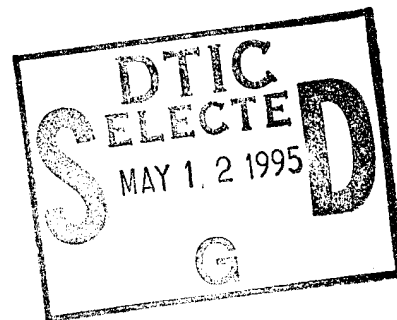
NATIONAL AIR INTELLIGENCE CENTER



RESEARCH ON SEVERAL PROBLEMS IN THERMAL DESIGN FOR
SPIN-STABILIZED GEOSTATIONARY SATELLITES

by

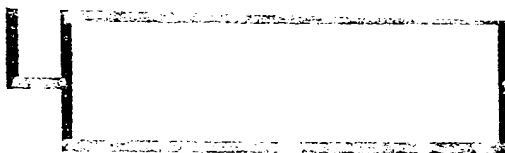
Guo Jiurong



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RESEARCH ON SEVERAL PROBLEMS IN THERMAL DESIGN FOR
SPIN-STABILIZED GEOSTATIONARY SATELLITES

Guo Jiurong

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ABSTRACT

This article carries out research on several problems associated with spin stabilized stationary satellite thermal design. These include selection of main heat radiation surfaces, heat control coating degradation, as well as further steps toward lightening the weight of heat control systems and so on.

SUBJECT TERMS: Synchronous satellite, Spin stabilized satellite, Thermal properties, Design.

I. FORWARD

In April 1984 and February 1986, we successfully launched, one after the other, two experimental communications satellites (hereafter called simply STW-1 and STW-2). These two spin stabilized type satellites have already been at their respective fixed position points in geosynchronous orbit more than 4 years and more than 2 years. Heat control systems provide good temperature environments [1] for satellite launch, positioning, and stable motion. Taking STW-2 as an example, most of the instruments and components are all in an extremely good temperature range of 10 - 25°C, completely matching originally specified design requirements. Table 1 extracts temperature data associated with several typical instruments.

* Numbers in margins indicate foreign pagination.
Commas in numbers indicate decimals.

TABLE 1 STW-2 TYPICAL INSTRUMENT TEMPERATURE VALUES °C
(1986.3.22)

1 仪 器 名 称	2 遥测温度	3 设计范围
4 消旋线路盒	13.84	-20 ~ +40
5 行波管 (B)	24.70	-20 ~ +70
6 行波管电源 (B)	22.0	-10 ~ +40
7 隧 放	17.95	0 ~ +30
8 蓄电池 (A)	14.0	0 ~ +30
9 二次能源 (B)	21.75	-20 ~ +50
10 应答机 (A)	21.77	-20 ~ +40

Key: (1) Instrument Nomenclature (2) Telemetry Temperature
(3) Design Range (4) Spin Suppression Circuit Box
(5) Traveling Wave Tube (B) (6) Traveling Wave Tube Power
Source (B) (7) Tunnel Discharge (8) Storage Battery (A)
(9) Secondary Power Source (B) (10) Answering Device (A)

In the last few years, telemetry data in a steady and unbroken stream has been sent back to the ground. Satellite temperature status has been closely watched throughout. On the basis of data accumulated on the two satellites in long term orbital motion, there are the conditions to carry out analytic probes of some problems associated with spin stabilized stationary satellite heat control systems in order to supply reference material for follow up thermal designs associated with the same type of satellite. Despite the fact that, in recent years, domestically and abroad, there have been great efforts to develop three axis stabilized model stationary satellites, in

such fields as communications, broadcasting, television, weather, as well as data relay and so on, however, as far as synchronous orbits are concerned, there is still no shortage of spin stabilized type satellites in great numbers.

II. MAIN HEAT RADIATION SURFACE SELECTION

Appropriately dispersing out dissipated amounts of heat as high as several hundred watts associated with instruments and components inside satellites is one of the key questions in satellite thermal design.

In the early stages, outside China, the main heat radiation surfaces associated with spin stabilized satellites were all selected on sun screens. Most typical representatives are the international communications satellite-IV and the U.S. Air Force tactical communications satellite (TACSAT-1). The schematic layout for international communications satellite-IV is as in Fig.1. Power dissipation within the satellite in question is approximately 90% concentrated in the spin suppression cabin. As far as the power associated with taking these amounts of heat and dispersing them out into space is concerned, this is primarily taken care of by the sun screens [2]. Sun screens are divided into two parts. The plate shaped part close to the spin axis opts for the use of aluminum plated polytetrafluorethylene thin film ($\alpha_s=0.16$, $\varepsilon=0.66$) to act as surface heat control coating. With regard to the cone shaped section close to the solar battery array, the outer surface is covered with a high efficiency silver plated quartz glass mirror ($\alpha_s=0.085$, $\varepsilon=0.80$).

Fig.1 International Communications Satellite-IV Lay Out Diagram

Key: (1) Sun Screen
(Plates) (2) Sun
Screen (Cone)
(3) Upper Solar
Battery Array
(4) Lower Solar
Battery Array
(5) Spin
Suppression Cabin

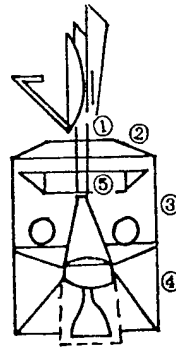
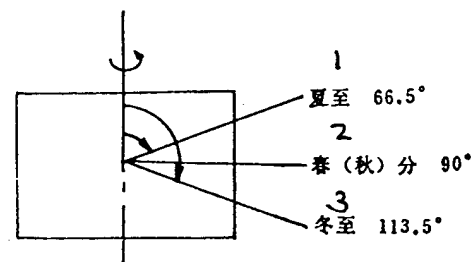


Fig.2 Changes in Stationary Satellite Solar Incidence Angles

Key: (1) Summer Solstice
(2) Spring (Autumn)
Equinox (3) Winter
Solstice



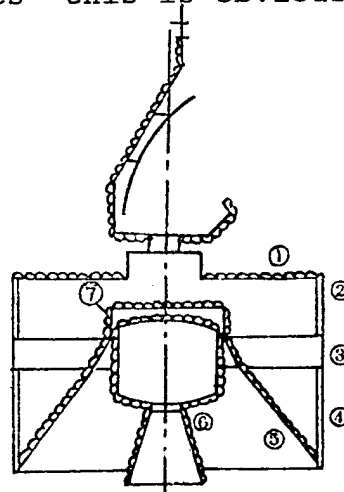
In fact, opting for the use of solar screens to act as main heat radiation surfaces is certainly not the ideal design.

First of all, stationary satellite solar incidence angles show obvious seasonal changes. Fig.2 clearly shows that, within one year, the range of changes in solar angle is $66.5^\circ - 113.5^\circ$. From the spring equinox to the summer solstice, the solar angle goes from 90° to 66.5° . Solar screens--from not receiving direct sunlight irradiation--gradually come to receive illumination. From the summer solstice to the autumn equinox, the solar angle goes from 66.5° to 90° . Solar screens--from receiving irradiation--gradually change to not receiving illumination. From the autumn equinox--going through the winter solstice--to the spring equinox of the second year, solar angles change from 90° to 113.5° and then back to 90° . During the period of this half year, solar screens--from beginning to end--do not receive

direct sunlight irradiation. Due to the fact that solar angles are not the same, there are changes in external heat flow, creating temperature fluctuations of large amplitude on solar screen surfaces. In the case of this situation--speaking in terms of heat radiation surfaces--this is obviously extremely disadvantageous.

Fig.3 STW-2 Heat Control Schematic

Key: (1) Solar Screen
(2) Upper Casing
(3) Belt (4) Lower Casing
(5) Heat Insulation Screen
(6) Apogee Engine
(7) Heat Insulation Material



Second, as far as the front ends of spin stabilized satellites are concerned, in the vicinity of sun screens there are often attached a certain number of antennas with various different individual shapes. They have unusually complicated thermal coupling relationships with sun screens. Whether it is analytical calculations or ground thermal simulation tests, they all have considerable difficulties, thus increasing the inexactitude of thermal design. Moreover, following along with development in satellite functions, antenna systems have a tendency to become more and more complicated. This will make solar screen heat dissipation efficiency clearly drop.

In the mid-1970's -- when China specified thermal control designs -- adequate verifications were gone through, and it was decided to give up on the commonly adopted designs abroad at that time which used solar screens as primary heat radiation surfaces, changing -- on the cylindrical sections of satellites -- to the special installation of a middle belt in order to radiate heat. See Fig.3. The advantage of this design lies in -- with the exception of shadow areas -- the belt always receiving solar

irradiation. Moreover, it will not be affected by interference associated with antennas and other such components. Temperature change amplitudes are small. This is an advantage for temperature control associated with instruments and components inside the satellite. Besides this, heat insulation measures were increased on solar screens, making the outer surface temperature fluctuations influencing instruments inside the satellite be reduced to minimum levels. /60

TABLE 2 SEASONAL VARIATIONS IN STW-2 SOLAR SCREEN TEMPERATURES

1 日期	1986.3.22	1986.6.19	1986.9.24	1986.12.25
2 季节	春 ⁵ 分	夏 ⁶ 至	秋 ⁷ 分	冬 ⁸ 至
3 太阳角(°)	90.08	66.47	90.63	113.85
4 外表面温度(°C)	-61.35	33.51	-65.15	-92.72

Key: (1) Date (2) Season (3) Solar Angle (4) Outer Surface Temperature (5) Spring Equinox (6) Summer Solstice (7) Autumn Equinox (8) Winter Solstice

The flight statuses of the two satellites demonstrate that the point of view in the analysis above is correct. This thermal control design gets good results.

Fig.2 gives STW-2 temperature data associated with solar screen outer surfaces in different seasons. It is possible to clearly see the influences created by solar angle changes.

TABLE 3 STW-2 BELT SKIN TEMPERATURE DATA

1 日期	1986.3.22	1986.6.19	1986.9.24	1986.12.25
2 季节	春 ⁵ 分	夏 ⁶ 至	秋 ⁷ 分	冬 ⁸ 至
3 太阳角(°)	90.08	66.47	90.63	113.85
4 腰带(1)(°C)	12.41	8.28	14.44	16.10
4 腰带(2)(°C)	-0.22	-2.35	1.55	2.91

Key: (1) date (2) season (3) Solar Angle (4) Belt
 (5) Spring Equinox (6) Summer Solstice (7) Autumn Equinox
 (8) Winter Solstice

Acting as a contrast, Table 3 gives STW-2 temperature data for two pieces of belt skin using different coatings. Seasonal changes associated with belt skin temperatures are very small. Among these are also included the influences of coating property degradation.

Table 4 gives daily change data for STW-2 solar screen temperatures on 6 February 1986. On that day, the solar angle was approximately 106°. Solar screens did not receive direct sun light irradiation. However, antennas relative to the sun rotate once every 24h. In one day, locations receiving irradiation change. Not only are temperatures associated with various parts of antennas themselves not uniform. Moreover--through radiation coupling relationships and reflected solar energies--there are clear influences on solar screen outer surface temperatures.

TABLE 4 DAILY CHANGES IN STW-2 SOLAR SCREEN TEMPERATURES

1 部位	2 时刻	8:15	9:00	10:00	11:00	14:00	15:00	16:00	17:00	21:00	22:00
3 外表面		-81.45	-80.36	-86.05	-86.05	-88.57	-89.89	-92.72	-91.28	-75.26	-75.26
4 内表面		6.86	7.62	6.86	—	—	—	—	—	7.62	7.62

Key: (1) Location (2) Time (3) Outer Surface (4) Inner Surface

From this, it is possible to see that, as far as solar screen outer surface temperatures are concerned, there are not only seasonal changes. Moreover, there are daily changes associated with a 24h cycle. Obviously, the two will both influence the stability of sun screen heat radiation function. If one takes solar screens to act as primary heat radiation surfaces, there will necessarily be created relatively large temperature changes associated with instruments and components inside satellites. At times when it is necessary to use solar screens to act as primary heat radiation surfaces, one should adequately take into account this disadvantageous factor.

With regard to new models of spin stabilized high capacity communications satellites which have been launched in the last few years abroad--for example, the international communications satellite VI and Anik-D [3], etc--in all cases, they did not opt again for the use of solar screens as primary heat radiation surfaces. It is generally recognized that this way to radiate heat does not have high efficiencies. Following along with increases in numbers of transmitters, power consumption within satellites increases daily. These satellites, in the same way without consultation, all installed radiators on satellite cylindrical sections possessing equivalent areas, that is, they opted for the use of belts to act as primary heat radiation surfaces.

III. HEAT CONTROL COATING PROPERTY DEGRADATION

As far as degradation of satellite heat control coatings in a space environment is concerned, that is, problems associated with rising solar absorption rates, they have already given rise to universal serious consideration and attention. Outside China, large amounts of reference materials have made reports on the results of coating ground tests and flight data. In conjunction with this, analysis and research has been carried out on /61 degradation mechanisms. A number of solution methods have also

been brought up [4]. However, these reports vary in their opinions even to the point of being mutually contradictory. When satisfactory answers have not yet been obtained, at the present time, it is only possible to rely on leaving adequate redundant margins when doing thermal design. For example, abroad, it is generally recognized that silver plated quartz glass mirrors have the most stable space properties. Its solar absorption surface measurement values are approximately 0.08. However, when designing stationary satellites with lives of 7-10 years, in the final phases, values are often selected as high as approximately 0.25.

With regard to satellites during periods of orbital motion, heat control coating solar absorption rates go up. This leads directly to the appearance of a gradual trend upward in satellite surface temperatures. In conjunction with this, it creates a corresponding temperature rise for instruments and components inside satellites. The most severe outcome will be that certain component temperatures will exceed high temperature limits associated with original design ranges, even to the point of influencing normal satellite operations.

Table 5 gives historical temperature variation values for key STW-1 structural members as well as instruments and components inside the satellite associated with spring equinox seasons. They reflect the levels of heat control coating property degradation. For three years, the general average temperature rise for instruments and components inside the satellite is approximately 5°C. It is worth pointing out that--no matter whether it was the satellite surface or instruments and components inside the satellite--the first year temperature rise was the most obvious. The second year gradually tended to gentle down. Third year changes were even smaller. In the fourth year, up to now, clear temperature changes have not yet been seen.

Table 6 gives STW-2 spring equinox temperature data for key components. Rising temperature trends appear in the same way. In two years, the general temperature rise for instruments and components inside the satellite was roughly 4°C.

The two satellites were both equipped with specialized coating test devices used in order to monitor coating property degradation. Table 7 and Table 8, respectively, give STW-1 and STW-2 coating test device test sample temperature data. Besides black anodized aluminum test sample temperatures basically not changing or dropping slightly and the appearance of coating "bleaching" effects, the temperatures of the rest of the test samples all showed a rising trend. This clearly shows that coating absorption rates have different levels of increase. Refer to Fig.4. Summing it all up, in accordance with the passage of time, the speed of coating degradation (solar absorption rate increase) becomes slightly gentler. Its trend matches up with the status of temperature changes for the whole satellite. The results of detailed analysis are the introduction to another specialized article.

From the flight data which is currently available, it is possible to obtain three key insights. First, it is necessary to pay adequately serious attention to the problem of heat control coating property degradation creating gradual increases in satellite temperature. Second, following along with the passage of time, coating absorption rates change and tendencies for satellite temperatures to go up gradually gentle out. Third, as far as actual temperature rise data for periods of STW orbital motion are concerned, they possess important reference value for the thermal design of China's follow on long life satellites of the same type.

TABLE 5 STW-1 KEY COMPONENT TEMPERATURE RISE VALUES OVER THE YEARS

1 部 位	2 时 间	第 一 年 3 1984.4~1985.3	第 二 年 4 1985.3~1986.3	第 三 年 5 1986.3~1987.3	三年合计温升值 6
7 6块腰带蒙皮 (铝光亮阳极化)		9.61	2.33	2.04	15.23
8 2块腰带蒙皮 (镀铝铈玻璃镜)		4.31	1.80	0.86	6.97
9 仪器盘附近20个仪器		3.62	1.05	0.22	4.89
10 上框平面3个仪器		2.08	0.32	0	2.40

Key: (1) Component (2) Time (3) First Year (4) Second Year (5) Third Year (6) Three Year Total Temperature Rise Value (7) 6 Pieces of Belt Skin (Bright Anodized Aluminum) (8) 2 Pieces of Belt Skin (Aluminum Plated Cerium Glass Mirror) (9) 20 Instruments in the Vicinity of the Instrument Panel (10) 3 Instruments on Flat Upper Rack Surfaces

TABLE 6 STW-2 KEY COMPONENT TEMPERATURE DATA

1 部 位	2 日 期	1986.3.22	1987.3.23	1988.3.24	两年温升值 3
4 6块腰带蒙皮 (镀光亮阳极化)		13.7	17.65	20.29	6.59
5 2块腰带蒙皮 (镀铝铈玻璃镜)		-0.62	1.89	3.72	4.34
6 腰带附近18个仪器		17.09	19.41	21.54	4.45
7 上框平面4个仪器		14.30	15.75	18.36	4.06

Key: (1) Component (2) Date (3) Two Year Temperature Rise Value (4) 6 Pieces of Belt Skin (Plated Bright Anodized) (5) 2 Pieces of Belt Skin (Aluminum Plated Cerium Glass Mirror) (6) 18 Instruments in the Vicinity of the Instrument Panel (7) 4 Instruments on Flat Upper Rack Surfaces

TABLE 7 STW-1 COATING TEST DEVICE SAMPLE TEMPERATURES

1 试片	2 日期	1984.4.21	1985.3.17	1986.3.20	1987.3.19	三年合计温升值 7
3 铝黑色阳极化		25.57	25.57	25.57	25.57	0
4 铝光亮阳极化		35.78	48.16	56.0	55.99	20.22
5 铝粉漆		23.09	31.55	36.53	36.53	13.44
6 涂料型二次镜		-7.32	20.43	28.29	32.85	40.17

Key: (1) Sample (2) Date (3) Black Anodized Aluminum
 (4) Bright Anodized Aluminum (5) Aluminum Powder Paint
 (6) Paint Type Secondary Mirror (7) Three Year Total
 Temperature Rise Value

TABLE 8 STW-2 COATING TEST DEVICE SAMPLE TEMPERATURES

1 试片	2 日期	1986.3.22	1987.3.23	1988.3.24	两年合计温升值 7
3 铝黑色阳极化		26.41	22.40	22.41	-4.01
4 S781-白漆		-34.75	-23.45	-15.30	19.45
5 铝粉漆		27.54	27.89	33.02	5.48
6 镀铝石英二次镜		-58.46	-54.20	-52.67	5.79

Key: (1) Sample (2) Date (3) Black Anodized Aluminum
 (4) S781-White Paint (5) Aluminum Powder Paint (6) Aluminum
 Plated Quartz Secondary Mirror (7) Two Year Total Temperature
 Rise Value

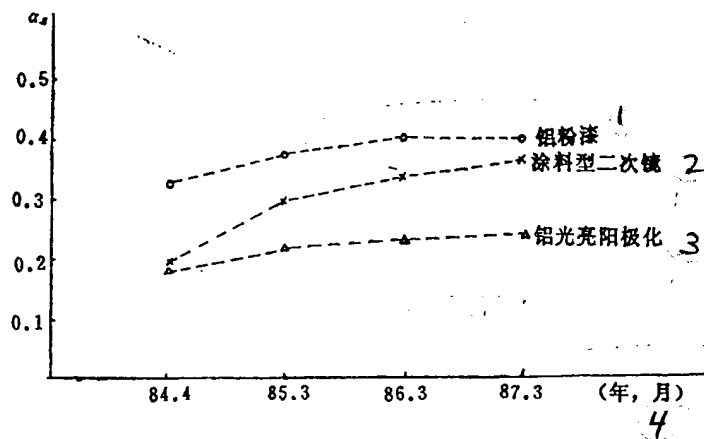


Fig.4 STW-1 Coating Test Device Sample Solar Absorption Rates

Key: (1) Aluminum Powder Paint (2) Paint Type Secondary Mirror
(3) Bright Anodized Aluminum (4) (Year, Month)

FURTHER STEPS IN REDUCING THE WEIGHT OF HEAT CONTROL SYSTEMS

Striving to reduce the weights of various components is an objective which is sought in every way possible by satellite designers. Heat control systems are no exception. A good deal of beneficial work has already been done for this.

Fig.9 gives STW-1 weight statistics results associated with heat control systems. The situation with STW-2 is roughly the same as this.

On the basis of realization experience from two satellites, there is a possibility of going through strenuous efforts to take further steps in saving on the weight of heat control systems, contributing to weight reduction in entire satellites. At the present time, relatively mature ways are:

1. Change the Composition of Multilayer Heat Insulation Materials

From Table 9, it is possible to know that the weight of multilayer heat insulation materials in heat control systems accounts for the largest percentage. In order to lighten this portion of weight, it has already been decided, in follow up satellites, to change the structure of multilayer insulation materials. Utilizing even thinner aluminum plated polyester thin films to act as radiation screens and even lighter nylon netting to be spacing layers, estimated total weight of multilayer heat insulation material can be lightened 20-30% compared to currently.

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2. Apogee Engine Heat Control Measures

In order to guarantee that apogee engines in transition orbit motion for periods from several tens of hours to more than 100 hours are, from beginning to end, placed within predetermined ignition temperature ranges (-20 -- $+40^{\circ}\text{C}$), it is necessary to opt for the use of effective thermal control measures. Currently, STW apogee engines are equipped with 18W electric heaters and multilayer heat insulation material reaching weights of 7.6kg. In conjunction with this, immediately before firing, independent ground temperature adjustments are carried out.

TABLE 9 STW-1 THERMAL CONTROL SYSTEM WEIGHT STATISTICS

1 部 件 名 称	2 重 量 (kg)	3 百分比 (%)
4 多层隔热材料	~14.0	50.3
5 太 阳 屏	3.8	13.7
6 隔 热 屏	5.7	20.6
7 电加热器	0.9	3.1
8 涂层及胶粘剂	2.0	7.2
9 热 管	0.6	2.2
10 地面调温管路	0.8	2.9
11 合 计	~27.8	100.0

Key: (1) Part Nomenclature (2) Weight (3) Percentage
 (4) Multilayer Heat Insulation Material (5) Solar Screen
 (6) Thermal Insulation Screen (7) Electric Heater
 (8) Coating and Adhesive (9) Heat Pipes (10) Ground
 Temperature Adjustment Tubing (11) Total

Table 10 gives STW-2 apogee engine temperature data associated with moments right before and at ignition. It is not difficult to see that, in the case of the principal components of apogee engines, average speeds of temperature drop during periods of transition orbit motion are smaller than 0.2°C/hr . If appropriate ground temperature adjustments are gone through, making initial temperatures associated with apogee engine take off times to be maintained in the vicinity of 30°C , then, on the basis of currently available temperature drop speed data, making relatively conservative estimates, even if transition orbit motion times go as long as 120h, at apogee engine ignition times, it is still possible to hold at above 6°C . There is still considerable margin before leaving lower limit temperature values. Because of this, the amount to use (layer number) associated with appropriately reducing apogee engine multiple layer heat insulation is capable of being realized.

TABLE 10 STW-2 APOGEE ENGINE TEMPERATURE DATA

1 日期	86.2.1	86.2.1	86.2.2	86.2.2	86.2.2	86.2.2	86.2.3	86.2.3
2 时刻			8:53	11:00	12:30	15:00	6:17	10:00
3 状态	临 ⁸ 射	上 ⁹ 升段	过 ¹⁰ 渡 轨 道					即将点火 ¹¹
4 上封头	30.23	27.94	28.72	27.94	27.94	27.94	25.69	24.97
5 柱段	28.02	25.74	23.63	22.95	22.95	22.95	20.29	19.65
6 下封头	30.16	28.75	25.83	25.14	25.14	24.45	20.50	19.87
7 喉部	25.07	23.38	25.16	26.07	26.07	26.07	22.51	20.81

Key: (1) Date (2) Time (3) Status (4) Upper Seal
 (5) Cylinder Section (6) Lower Seal (7) Throat Section
 (8) Just Before Launch (9) Ascent Phase (10) Transition
 Orbit (11) On the Point of Ignition

It is worth pointing out that international communications satellite-IV apogee engine codeployed electric heater powers reach over 70W. In the initial design period of China's STW, there was anxiety over power sources. Apogee engine heater powers were limited to 18W. The two are very far from each other. In fact, the flight status of the two satellites clearly shows that transition orbit power sources have relatively large margins. On investigation, the reasons for this are, on the one hand, that, in initial orbital entry periods, solar battery array conversion efficiencies are high. Output powers are large. On the other hand, transitional orbit stage satellite effective loads have not yet completely come into operation. Satellite loads are relatively small. If one makes rational use of the abundant electric power in early stages, appropriately increasing apogee engine heater powers, then, savings on multilayer heat insulation material weight will be more considerable. This, then, requires, when doing overall design, across the board considerations and arrangements planned as a whole. Making use

of optimization design methods, it is possible to make apogee engine heat control measures, in the two areas of weight and power consumption, realize an optimum combination.

3. Changing Heat Insulation Screen Materials

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As far as the primary functions of heat insulation screens are concerned, one is to prevent high temperature plumes at the time of apogee engine ignition influencing instruments and components inside satellites. A second is to reduce as much as possible the routine thermal coupling of instruments and components inside satellites to the space environment. STW heat insulation screens are made from such high temperature resistant materials as stainless steel foil, nickel foil, and high silicon oxygen cloth as well as medium temperature and low temperature multilayer heat insulation materials. Flight data clearly shows that, after apogee engine ignition, the telemetry recorded value for maximum heat insulation screen surface temperatures is approximately 300°C. However, sustainment times are not long. On these grounds, it is possible to consider--on the supposition of there remaining single layer stainless steel foil (or, alternatively, using other metal foil materials such as titanium), eliminating interior layer nickel foil and high silicon oxygen cloth, substituting with the use of such materials as aluminum plated polyamide thin films, to reach the objective of lightening weight.

To summarize what has been discussed above, after going through further analysis, calculations, and empirical verifications, with regard to making appropriate corrections in STW thermal designs, there is a possibility of making heat control system weights 4-6kg lighter than the original or even more.

V. CONCLUSIONS

Up to the present time, heat control system operations associated with China's two experimental communications satellites have been normal. In conjunction with this, key data has already been obtained in a number of areas where ground experimental methods do not exist, accumulating large amounts of precious first hand material.

As far as heat control systems associated with the two satellites are concerned, plans are rational, designs are correct, and results are good. Various types of heat control materials and components (for example, heat tubes, polyamide thin film type electric heaters, armored high temperature electrical heating wire, and multilayer heat insulation materials appropriate for use in different temperature zones) have already been actually tested for relatively long periods in synchronous orbits. The quality is reliable. Properties are stable. With regard to actual utilization properties associated with various types of heat control coatings in space environments, we are just in the midst of progressively increasing in-depth knowledge and grasp. Because of this, on the foundation of summarized experience, it is possible to take thermal design levels and raise them another step. Moreover, there are the conditions for developing spin stabilized stationary satellite heat control systems with more advanced indices and longer useful life.

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